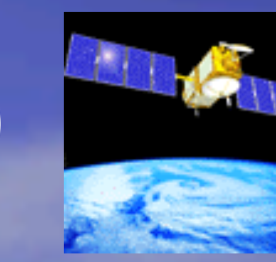
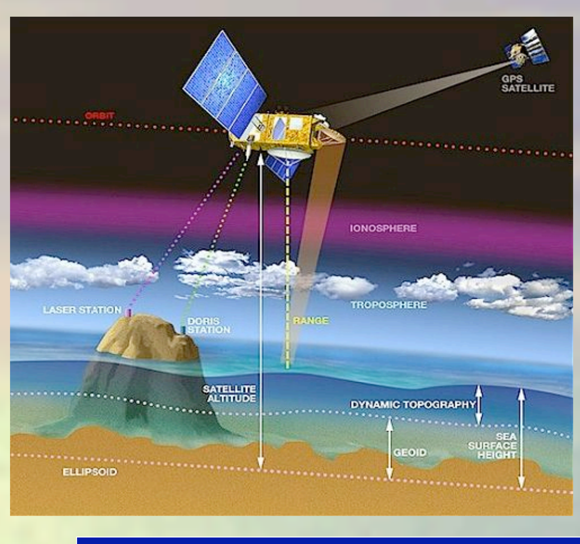


Making Earth System data records for Use in Research Environments (MEaSUREs)

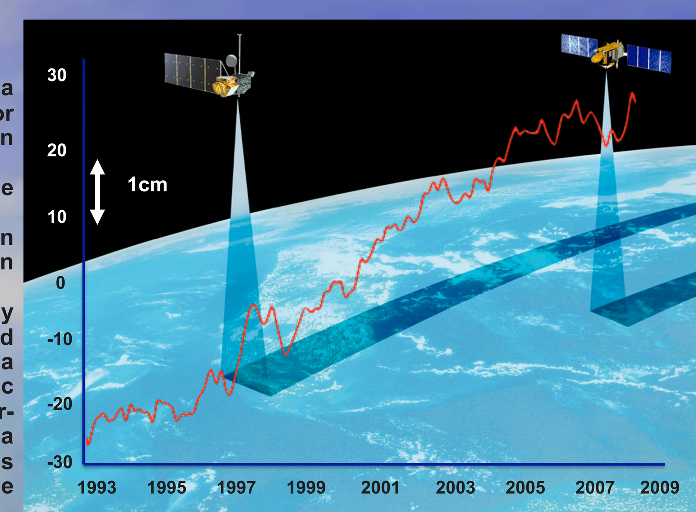
Integrated Multi-Mission Altimeter Data for Climate Research

B. Beckley, N. Zelensky, S. Holmes - SGT, Inc.
F. Lemoine, S. Luthcke, R. Ray – NASA/GSFC
D. Jacob – UMBC
S. Desai, S. Brown - JPL
G. Mitchum – Univ. of S. Florida
R.S. Nerem - Univ. of Colorado

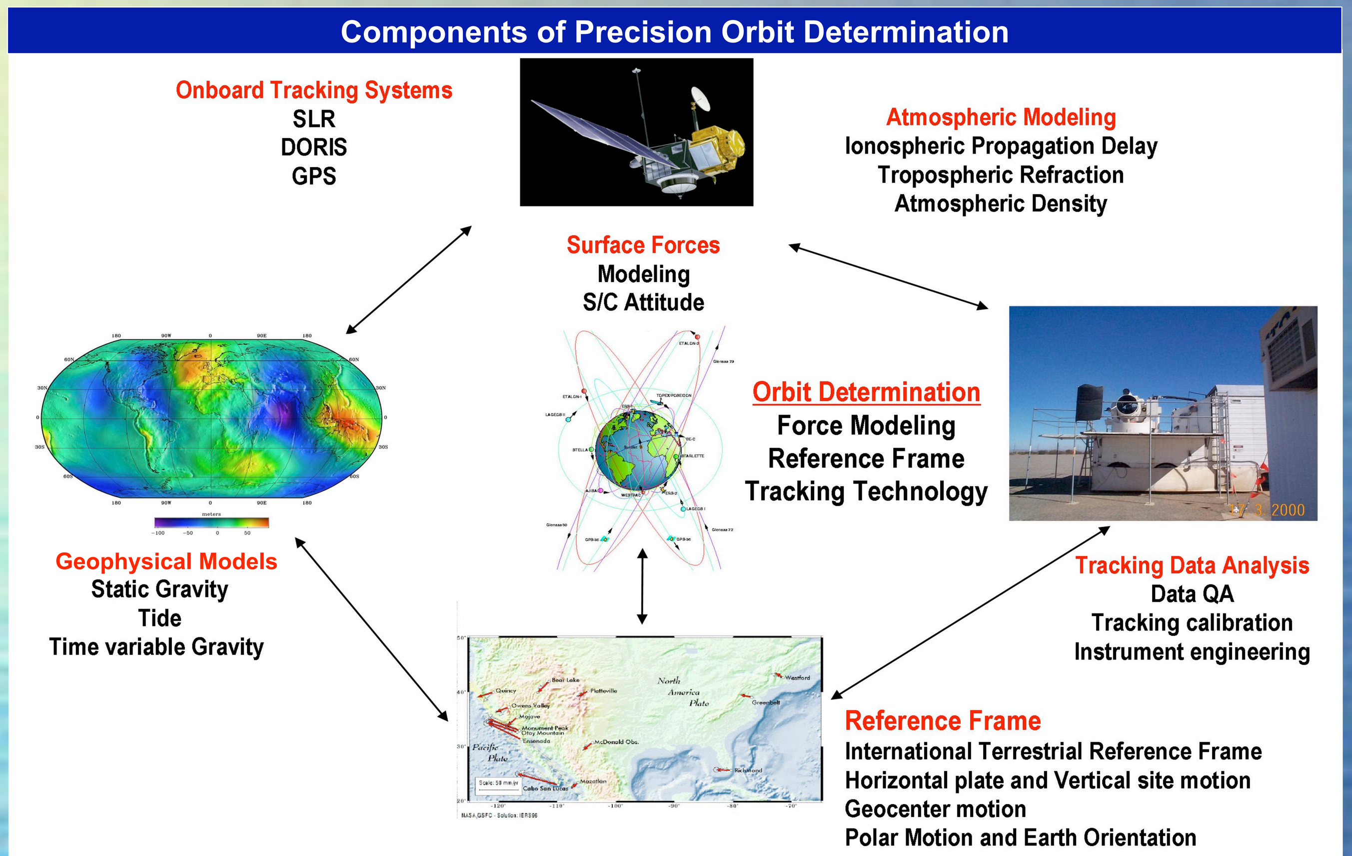
Pathfinder Legacy



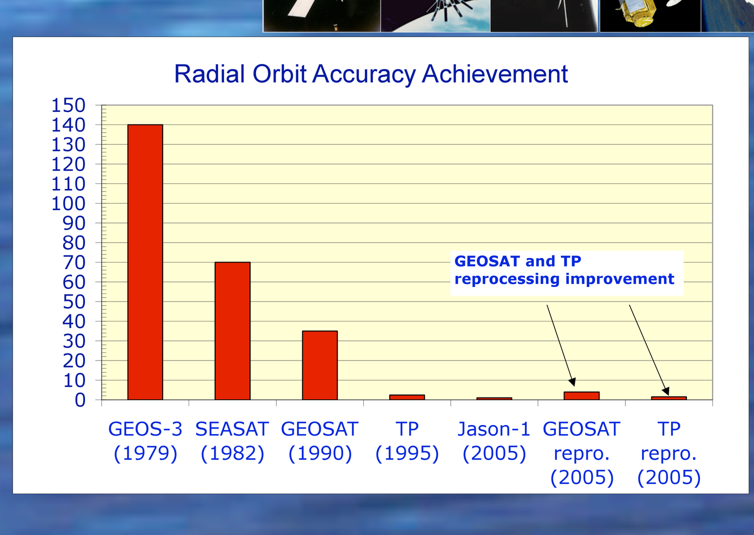
- Satellite altimetry measures sea surface topography, a proxy for ocean heat content and ocean circulation.
- The oceans are the memory of the climate system.
- Monitoring changes in global mean sea level requires inter-mission consistency.
- The goal of this work is to apply the best possible physically-based corrections to each dataset within a consistent well defined geodetic reference frame, and produce inter-decadal sea level time series, so a change in time can be interpreted as a change in the ocean, not in the measurement system.



Components of Precision Orbit Determination



The measurement of mean sea-level change from satellite altimetry requires an extreme stability of the altimeter measurement system since the signal being measured is at the level of a few mm/yr. This means that the orbit and reference frame within which the altimeter measurements are situated, and the associated altimeter corrections, must be stable and accurate enough to permit a robust MSL estimate. Foremost, orbit quality and consistency are critical to satellite altimeter measurement accuracy. The orbit defines the altimeter reference frame, and orbit error directly affects the altimeter measurement. Orbit error remains a major component in the error budget of all past and present altimeter missions. For example, inconsistencies in the ITRF used to produce the precision orbits at different times cause systematic inconsistencies to appear in the multi-mission timeframe between TOPEX and Jason-1. However, with recent improvements in the satellite force models, reference systems, and modeling strategies, the orbit can be significantly improved as has been shown for GFO and T/P. Dramatic improvements foreseen in gravity field models anticipated from the GRACE Mission are currently being realized, offering a very significant reduction in orbit error, including those which are of special concern given they are geographically correlated, yet mission specific. In this presentation we provide a status report on our progress to provide a consistent precise orbit that will geodetically tie all missions.



POE ORBIT AVAILABILITY

We will by year's end place an accurate and consistent set of our latest GSFC SLR/DORIS dynamic replacement orbits for OSTM (Jason-2), Jason-1, and TOPEX on our anonymous ftp site:

dirac.gsfc.nasa.gov

pub/earth/repro-jason/ostm/ gsfc_ja2_poe_std0905.$cycle.Z	Jason-2 $cycle=001-044
pub/earth/repro-jason/swt08/ gsfc_poe_std0905.$cycle.Z	Jason-1 $cycle=001-259
pub/earth/repro-topex/swt08/ gsfc_poe_std0905.$cycle.Z	TOPEX $cycle=001-446

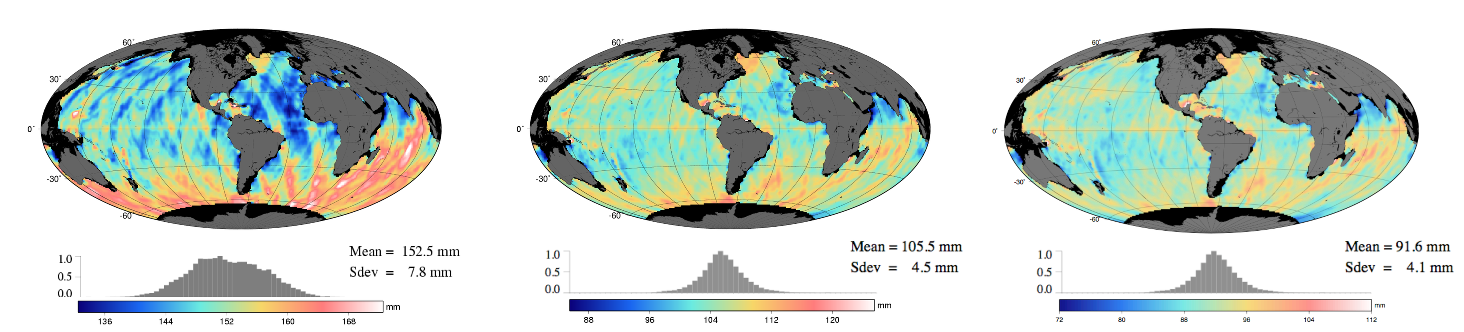
GSFC POD Model Standards May 2009: std0905

(changes from std0809 in red)

Reference frame and displacement of reference points			
SLR	SLRF2005 + LPOD2005 (version 11)		
DORIS	DPOD2005 (version 1.4)		
Earth tide	IERS2003		
Ocean loading	GOT4.7 all stations		
Tidal CoM &EOP	GOT4.7: VLBI high frequency terms		
EOP	IERS Bulletin A daily (consistent with ITRF2005)		
Precession / Nutation	IAU2000		
Gravity			
Static	Eigen-GL04s		
Time varying	Linear C20-dot, C21-dot, S21-dot (IERS2003) + 20x20 annual terms from GRACE		
Atmospheric	ECMWF, 50x50@6hrs		
Tides	GOT4.7 20x020 (ocean); IERS2003 (Earth)		
Satellite Surface Forces and attitude			
Albedo /IR	Knocke-Ries-Tapley (1988)		
Atmospheric drag	MSIS86		
Radiation pressure	TOPEX	Jason-1	Jason-2
	tuned 8-panel	UCL	Jason-1 8-panel
Radiation scale coeff.	C_R = 1.0	C_R = 1.0	C_R = 0.916 (tuned)
Attitude	Nominal Yaw; quatern. off-nominal	Nominal Yaw	Quaternions
Tracking data and parameterization			
Tracking data	SLR/DORIS (Jason1 DORIS corrected for SAA)		
Troposphere model	SLR: Mendes-Pavlis; DORIS: GPT + GPS/Neill		
Parameterization	Drag/8 hrs + opr along & cross-track /24 hrs + DORIS time bias /arc; 10-day arc dynamic solution		
Antenna reference	TOPEX	Jason-1	Jason-2
SLR	LRA model	tuned offset	pre-launch

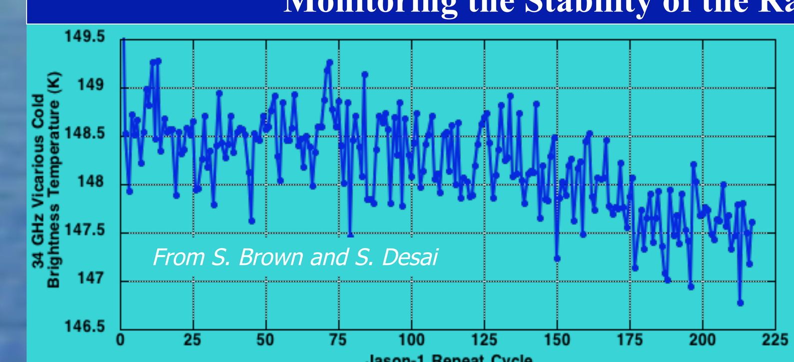
Jason - TOPEX Mean Sea Surface Height

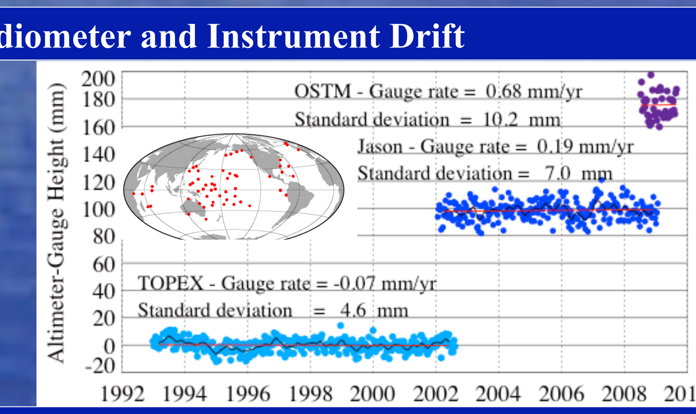
Verification Phase



Images above show progressive improved agreement of Jason/TOPEX mean SSH during the verification phase. SSH differences in left image are based on TOPEX MGDR_B (JGM3 orbits, CSR95 terrestrial reference frame), and Jason GDR_A (JGM3 orbits, ITRF2000). In the middle image the SSH is based on GSFC ITRF2000 (GGM02c) replacement orbits for both TOPEX and Jason GDR_A. In the right image the SSH is based on GSFC ITRF2005 (GGM02c) replacement orbits for both TOPEX and Jason GDR_B. Improved agreement has been realized with recently developed GSFC std0905 orbits with POD standards more consistent with recent Jason-1 GDR_C standards.

Monitoring the Stability of the Radiometer and Instrument Drift

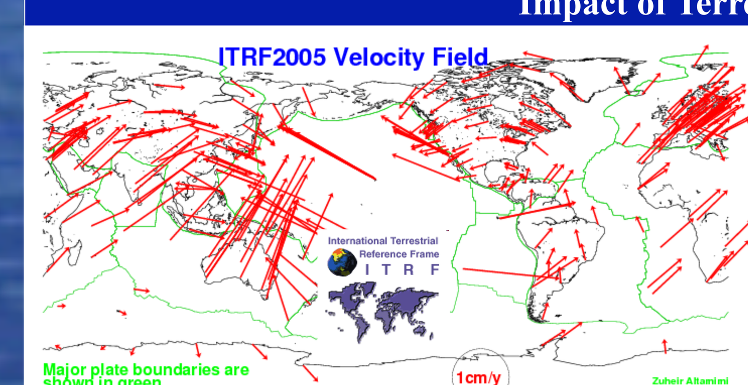


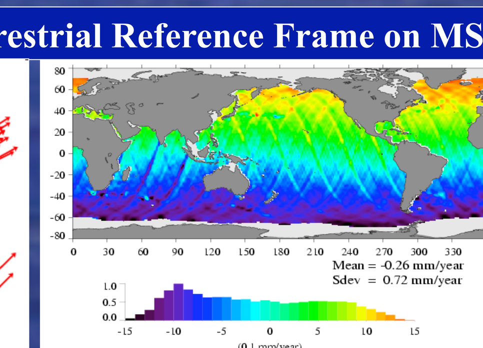


Adjusted for inter-mission biases derived from verification phases.

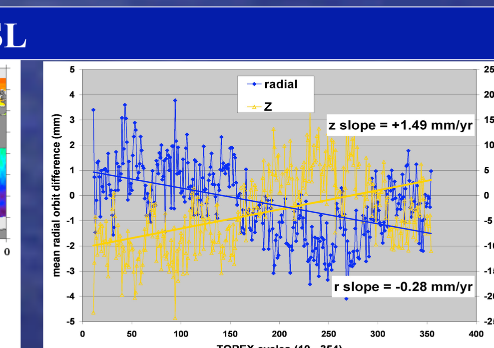
Left Figure: JMR 34 GHz brightness temperatures had drifted ~ 1K shortly after GDR_B re-calibration (from cycle 127-212). Impact is ~ +0.9 mm/yr drift in JMR wet path delay measurements since cycle 127 (S. Brown and S. Desai, 2008). Recent recalibration of the JMR for revised Jason-1 GDR_C has reduced overall estimated drift in path delay correction by 0.3 mm/yr. Right Figure: TOPEX and Jason-1 sea surface height variations are compared to tide gauge variations from 64 sites. Altimeter SSH values are based on GSFC ITRF2005 (Eigen_g104s) "std0905" orbits, and most recent recalibrated TMR and JMR wet troposphere range corrections. Estimated instrument bias derived from tide gauge comparisons are consistent with global mean collinear differences during the verification phases.

Impact of Terrestrial Reference Frame on MSL





Regional TOPEX (1993-2002) SSH trend differences from direct impact of the ITRF2005 (GGM02C) minus CSR95 (JGM3) orbit differences.



R slope / Z slope = -0.28 mm/yr / 1.49 mm/yr
MSL rate error = - 0.19 x TZ (mm/yr)
Where TZ is the mean orbit rate error in Z.

ITRF is an estimate of station positions and velocities for a given tracking/geodetic technology: SLR, DORIS, GPS, VLBI. Co-located sites link the technologies. It is a realization of an ideal Terrestrial Reference System whose origin is close to the geocenter. Over time the ITRF is expected to improve by including more and possibly better data in the solution. Although both highly accurate, systematic differences between ITRF2000 and ITRF2005 realizations affect POD, and highlight the importance for accuracy and stability in the ITRF. Further improvements are currently being realized with the recent release of ITRF2008. Global and regional MSL estimates derived from multi-mission altimeter data are impacted by inconsistencies in the terrestrial reference frame realization (Beckley, et. al., 2007).

Ocean Tide Modeling

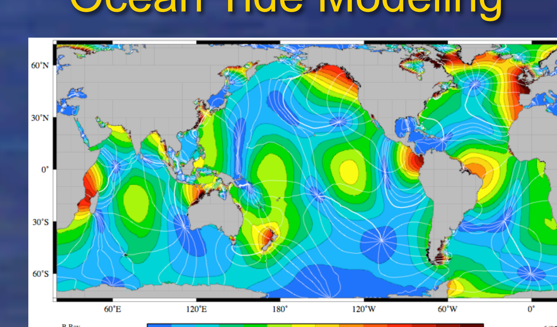


FIGURE: AMPLITUDE AND PHASE OF M2 TIDAL COMPONENT

Major Tidal Constituents

Semi-diurnal
- M_2 principal lunar
- S_2 principal solar
- N_2 larger lunar elliptic
- K_2 luni-solar

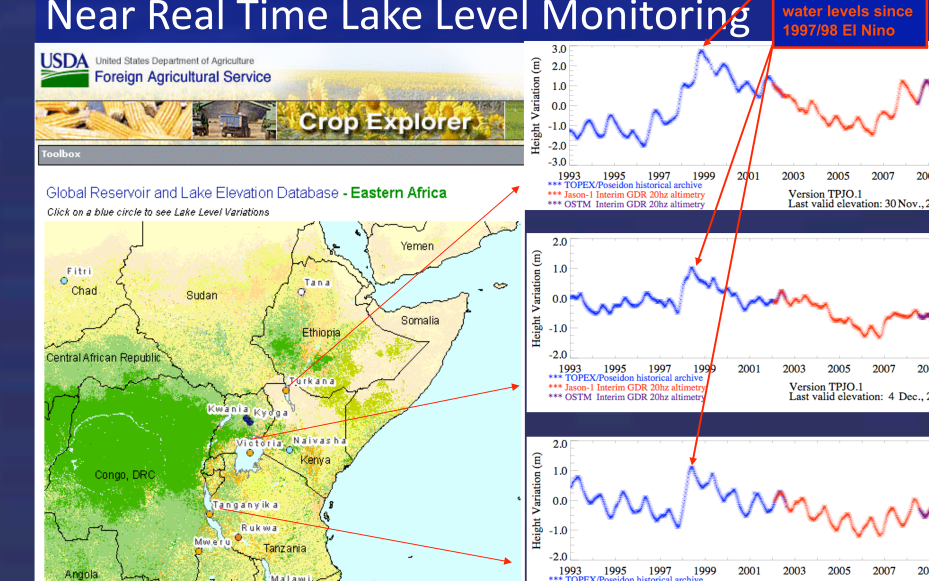
Diurnal
- K_1 luni-solar
- O_1 principal lunar
- P_1 principal solar
- Q_1 larger lunar elliptic

And recent addition of:
S_1 solar diurnal and M_4 barotropic

PI Richard Ray (GSFC) developed the recently revised GOT4.7 Ocean Tide Model derived from T/P, Jason-1, ERS and GFO altimetry; a significant improvement over all previous versions (1-2 cm accuracy in the open ocean), especially for the larger coastal tides.

Near Real Time Lake Level Monitoring

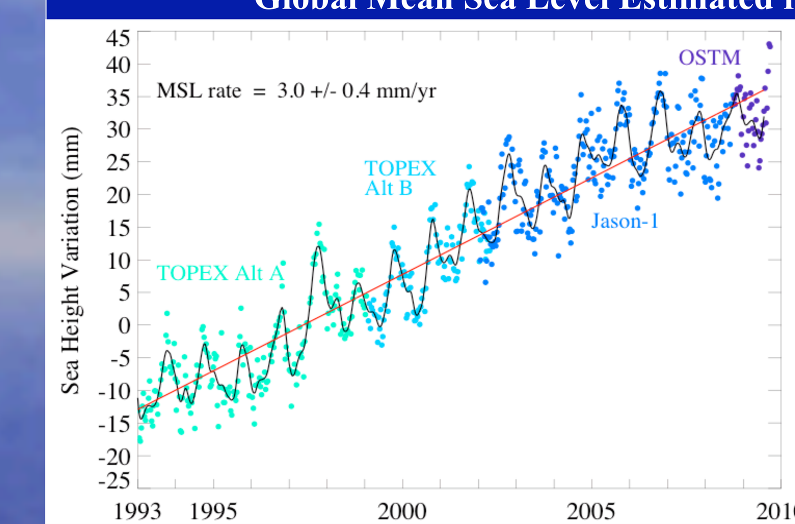
Decrease in lake water levels since 1997/98 El Nino

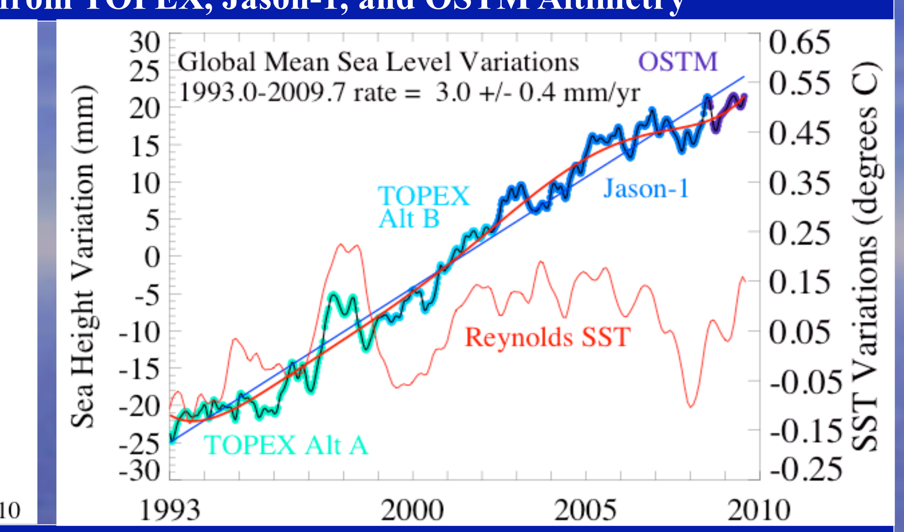


Reprocessed altimeter data better enables the monitoring of lake levels for the Foreign Agriculture Service under the U.S. Department of Agriculture for crop predictions and irrigation management.

Acknowledgements: The authors would like to thank PODAAC and CNES for providing AVHRR SST data and revised GDR data. This research is supported by the NASA MEaSURES Project, the Ocean Surface Topography Science Working Team, and the EOS Interdisciplinary Data Science Project.

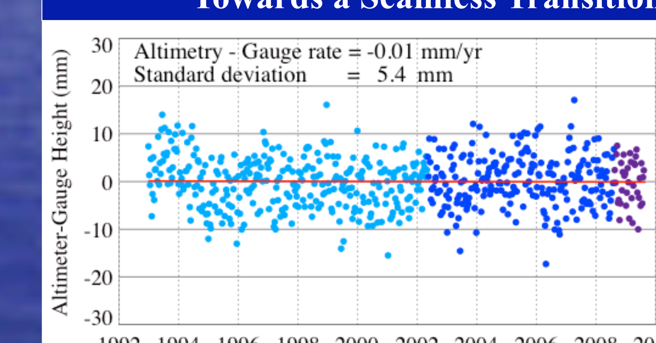
Global Mean Sea Level Estimated from TOPEX, Jason-1, and OSTM Altimetry

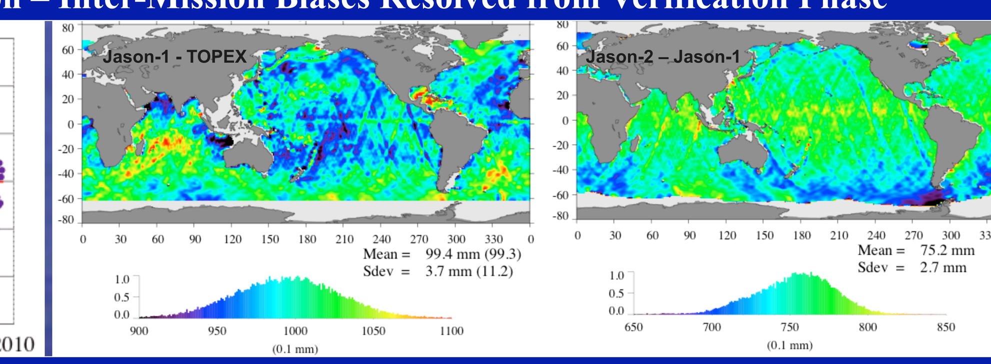




Left Image: Global mean SSH variations from TOPEX, Jason-1, and OSTM with respect to 1993 – 2002 mean are plotted every 10 days. The solid black line is the sea surface height variation with a 60-day Hanning filter applied revealing the annual cycle. Right Image: The global mean sea level rate is estimated from linear fit (blue line) after removal of annual and semi-annual signal. The MSL rate over the entire time span is 3.0 ± 0.41 mm/yr. SSH values throughout entire series are based on consistent GSFC ITRF2005 (Eigen_g104s) std0905 orbits, recent recalibration of TMR and JMR, MOG2d barometric correction applied. MSL rate error reported above is the root-square sum of the tide gauge precision and the variance of the global mean SSH variations about the linear fit. The red line is monthly mean sea surface temperature variations from Reynolds climatology.

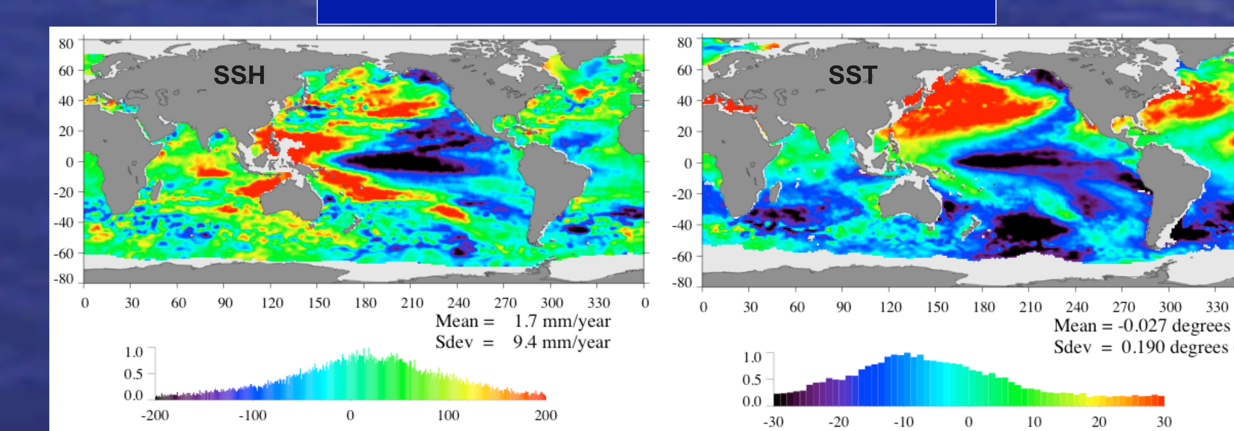
Towards a Seamless Transition – Inter-Mission Biases Resolved from Verification Phase





Left figure: Inter-mission bias adjustments derived from the Jason-1 and Jason-2 verification-phase collinear SSH differences have been applied to form a "single mission" time series to estimate the stability of the 17-year sea-surface height record. Right figure: Estimates of the Jason-1/TOPEX and Jason-2/Jason-1 intermission bias are derived from SSH collinear differences during their respective verification phase. The inter-mission bias estimates derived from the SSH collinear differences agree well with the tide gauge derived estimates.

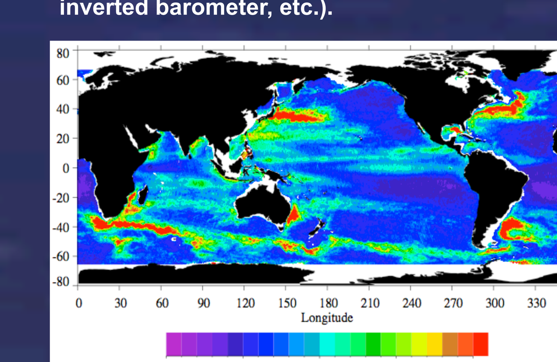
Recent Mean Sea Level and SST Trends 2004.0 – 2009.0



Left image: Regional MSL variations derived from Jason-1&2 altimetry over the period of 2004 through 2008. Right image: Regional sea surface temperature (SST) variations derived from Pathfinder AVHRR data (Casey, et al., 2010). As noted in the global mean sea level estimates above, over the last several years global mean sea level trends have "leveled off" due in part due an extended La Nina period, with a negative global mean SST trend.

Data Structure

- Along-track GDR repeat data aligned to nominal 1Hz geo-referenced locations by re-sampling 20Hz (10Hz) data essentially providing a global network of nearly ½ million tide gauges.
- SSH anomaly product output as direct access binary indexed in 3-dimensions based on orbit revolution, along-track index, and repeat cycle allowing spatial and temporal sampling and updates.
- 3-D structure provides capability for user to readily make revisions to SSH file based on similar structured auxiliary files for individual range or geophysical corrections (i.e. ocean tide model, sea state bias model, inverted barometer, etc.).



High resolution sea surface height variability generated from combined T/P and ERS sea surface heights at geo-referenced locations.

Transition to NetCDF

Advantages:
- Self Describing Format
- Efficient Data Model - Datasets are not too big
- Variety of Tools available
- Append (Add additional cycles)
- NetCDF classic Proposed ESDSWG SPG Standard (ESDS-RFC-011)
- CF RFC will be submitted to SPG in the near future

Data File Divided in to four sections:
- Variable Definitions and Dimensions
- Details: Source GDR, Reprocessing Procedures
- Data
- Process Updates

Distribution by JPL PODAAC
- Early 2010 T/P+Jason-1&2 product release

Fall AGU 2009
Poster IN43C-1168